

Connexions

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Electrodynamics: Alternating current, inductance and capacitance

Module by: [Free High School Science Texts Project](#).

Alternating Current

Most students learning about electricity begin with what is known as *direct current* (DC), which is electricity flowing in a constant direction. DC is the kind of electricity made by a battery, with definite positive and negative terminals.

However, we have seen that the electricity produced by some generators alternates and is therefore known as *alternating current* (AC). The main advantage to AC is that the voltage can be changed using transformers. That means that the voltage can be stepped up at power stations to a very high voltage so that electrical energy can be transmitted along power lines at low current and therefore experience low energy loss due to heating. The voltage can then be stepped down for use in buildings and street lights.

NOTE: Interesting Fact :

In South Africa alternating current is generated at a frequency of 50 Hz.

The circuit symbol for alternating current is:

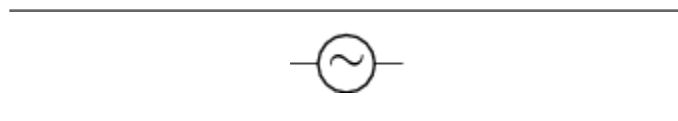


Figure 1

Graphs of voltage against time and current against time for an AC circuit are shown in [Figure 2](#) (#uid23)

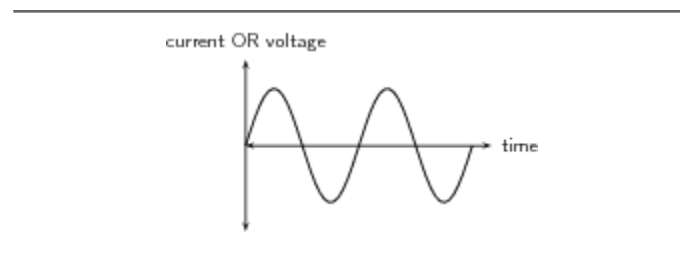


Figure 2: Graph of current or voltage in an AC circuit.

In an ideal DC circuit the current and voltage are constant. In an AC circuit the current and voltage vary with time. The value of the current or voltage at any specific time is called the *instantaneous current or voltage* and is calculated as follows:

$$\begin{aligned} i &= I_{max} \sin(2\pi ft + \phi) \\ v &= V_{max} \sin(2\pi ft) \end{aligned} \quad (1)$$

i is the instantaneous current. I_{max} is the maximum current. v is the instantaneous voltage. V_{max} is the maximum voltage. f is the frequency of the AC and t is the time at which the instantaneous current or voltage is being calculated.

The average value we use for AC is known as the root mean square (rms) average. This is defined as:

$$\begin{aligned} I_{rms} &= \frac{I_{max}}{\sqrt{2}} \\ V_{rms} &= \frac{V_{max}}{\sqrt{2}} \end{aligned} \quad (2)$$

Since AC varies sinusoidally, with as much positive as negative, doing a straight average would get you zero for the average voltage. The rms value by-passes this problem.

Exercise - alternating current

1. Explain the advantages of alternating current.
2. Write expressions for the current and voltage in an AC circuit.
3. Define the rms (root mean square) values for current and voltage for AC.
4. What is the period of the AC generated in South Africa?
5. If V_{max} at a power station generator is 340 V AC, what is the mains supply (rms voltage) in our household?
6. Draw a graph of voltage vs time and current vs time for an AC circuit.

Capacitance and inductance

Capacitors and inductors are found in many circuits. Capacitors store an electric field, and are used as temporary power sources as well as to minimize power fluctuations in major circuits. Inductors work in conjunction with capacitors for electrical signal processing. Here we explain the physics and applications of both.

Capacitance

You have learnt about capacitance and capacitors in Grade 11.

In this section you will learn about capacitance in an AC circuit. A capacitor in an AC circuit has *reactance*. Reactance in an AC circuit plays a similar role to resistance in a DC circuit. The reactance of a capacitor X_C is defined as:

$$X_C = \frac{1}{2\pi fC} \quad (3)$$

where C is the capacitance and f is the AC frequency.

If we examine the equation for the reactance of a capacitor, we see that the frequency is in the denominator. Therefore, when the frequency is low, the capacitive reactance is very high. This is why a capacitor blocks the flow of DC and low frequency AC because its reactance increases with decreasing frequency.

When the frequency is high, the capacitive reactance is low. This is why a capacitor allows the flow of high frequency AC because its reactance decreases with increasing frequency.

Inductance

Inductance (measured in henries, symbol H) is a measure of the generated emf for a unit change in current. For example, an inductor with an inductance of 1 H produces an emf of 1 V when the current through the inductor changes at the rate of $1 \text{ A} \cdot \text{s}^{-1}$.

An inductor is a passive electrical device used in electrical circuits for its property of inductance. An inductor is usually made as a coil (or solenoid) of conducting material, typically copper wire, wrapped around a core either of air or of ferromagnetic material.

Electrical current through the conductor creates a magnetic flux proportional to the current. A change in this current creates a change in magnetic flux that, in turn, generates an emf that acts to oppose this change in current.

The inductance of an inductor is determined by several factors:

- the shape of the coil; a short, fat coil has a higher inductance than one that is thin and tall.
- the material that the conductor is wrapped around.
- how the conductor is wound; winding in opposite directions will cancel out the inductance effect, and you will have only a resistor.

The inductance of a solenoid is defined by:

$$L = \frac{\mu_0 AN^2}{l} \quad (4)$$

where μ_0 is the permeability of the core material (in this case air), A is the cross-sectional area of the solenoid, N is the number of turns and l is the length of the solenoid.

DEFINITION 1: Permeability

Permeability is the property of a material which describes the magnetisation developed in that material when excited by a source.

NOTE: Interesting Fact :

The permeability of free space is $4\pi \times 10^{-7}$ henry per metre.

EXERCISE 1: Inductance I

Determine the inductance of a coil with a core material of air. A cross-sectional area of $0,3\text{m}^2$, with 1000 turns and a length of 0,1 m

SOLUTION

Step 1. **Determine how to approach the problem :**

We are calculating inductance, so we use the equation:

$$L = \frac{\mu_0 AN^2}{l} \quad (5)$$

The permeability is that for free space: $4\pi \times 10^{-7}$ henry per metre.

Step 2. **Solve the problem :**

$$\begin{aligned} L &= \frac{\mu_0 AN^2}{l} \\ &= \frac{(4\pi \times 10^{-7})(0,3)(1000)}{0,1} \\ &= 3,8 \times 10^{-3} \text{ H/m} \end{aligned} \quad (6)$$

Step 3. **Write the final answer :**

The inductance of the coil is $3,8 \times 10^{-3}$ H/m.

EXERCISE 2: Inductance II

Calculate the inductance of a 5 cm long solenoid with a diameter of 4 mm and 2000 turns.

SOLUTION

Step 1. **Think about the problem :**

Again this is an inductance problem, so we use the same formula as the worked example above.

$$r = \frac{4\text{mm}}{2} = 2\text{mm} = 0,002\text{m} \quad (7)$$

$$A = \pi r^2 = \pi \times 0,002^2 \quad (8)$$

$$\begin{aligned} L &= \frac{\mu_0 AN^2}{l} \\ &= \frac{4\pi \times 10^{-7} \times 0,002^2 \times \pi \times 2000^2}{0,05} \\ &= 0,00126\text{H} \\ &= 1,26\text{mH} \end{aligned} \quad (9)$$

An inductor in an AC circuit also has a reactance, X_L . Reactance is the property of an inductor that opposes the flow of AC current. Reactance is defined by:

$$X_L = 2\pi fL \quad (10)$$

where L is the inductance and f is the frequency of the AC.

If we examine the equation for the reactance of an inductor, we see that inductive reactance increases with increasing frequency. Therefore, when the frequency is low, the inductive reactance is very low. This is why an inductor allows the flow of DC and low frequency AC because its reactance decreases with decreasing frequency.

When the frequency is high, the inductive reactance is high. This is why an inductor blocks the flow of high frequency AC because its reactance increases with increasing frequency.

Exercise - capacitance and inductance

1. Describe what is meant by reactance.
2. Define the reactance of a capacitor.
3. Explain how a capacitor blocks the flow of DC and low frequency AC but allows the flow of high frequency AC.
4. Describe what is an inductor.
5. Describe what is inductance.
6. What is the unit of inductance?
7. Define the reactance of an inductor.
8. Write the equation describing the inductance of a solenoid.
9. Explain how an inductor blocks high frequency AC, but allows low frequency AC and DC to pass.

Summary

1. Electrical generators convert mechanical energy into electrical energy.
2. Electric motors convert electrical energy into mechanical energy.

3. There are two types of generators - AC and DC. An AC generator is also called an alternator.
4. There are two types of motors - AC and DC.
5. Alternating current (AC) has many advantages over direct current (DC).
6. Capacitors and inductors are important components in an AC circuit.
7. The reactance of a capacitor or inductor is affected by the frequency of the AC.

End of chapter exercise

1. [SC 2003/11] Explain the difference between alternating current (AC) and direct current (DC).
2. Explain how an AC generator works. You may use sketches to support your answer.
3. What are the advantages of using an AC motor rather than a DC motor.
4. Explain how a DC motor works.
5. At what frequency is AC generated by Eskom in South Africa?
6. **IEB 2001/11 HG1: - Work, Energy and Power in Electric Circuits** Mr. Smith read through the agreement with Eskom (the electricity provider). He found out that alternating current is supplied to his house at a frequency of 50 Hz. He then consulted a book on electric current, and discovered that alternating current moves to and fro in the conductor. So he refused to pay his Eskom bill on the grounds that every electron that entered his house would leave his house again, so therefore Eskom had supplied him with nothing! Was Mr. Smith correct? Or has he misunderstood something about what he is paying for? Explain your answer briefly.
7. What do we mean by the following terms in electrodynamics?
 1. inductance
 2. reactance
 3. solenoid
 4. permeability

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